United States
Department of
Agriculture

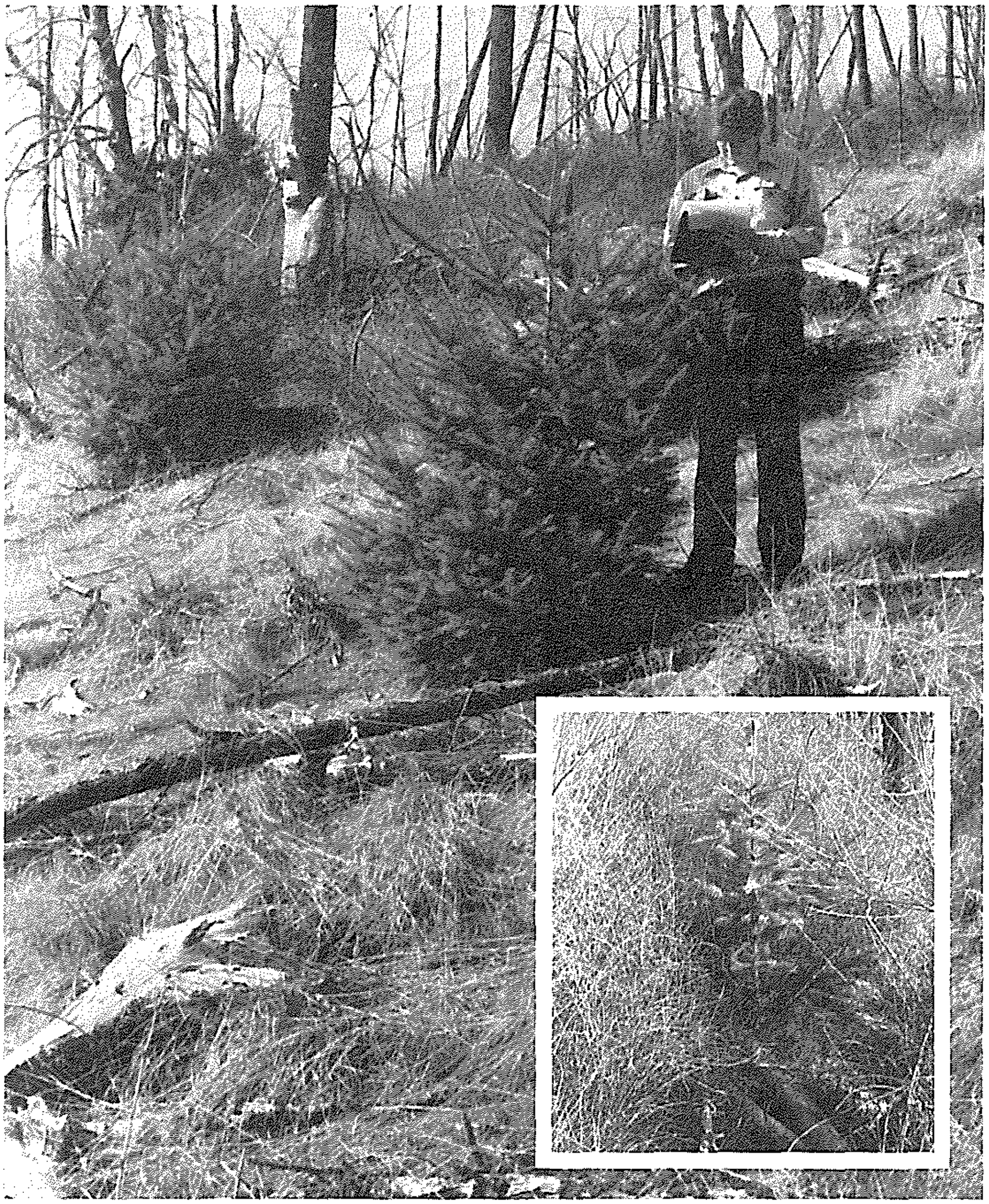
Forest Service

**Pacific Southwest
Forest and Range
Experiment Station**

Research Paper
PSW-182

Release of Douglas-Fir Seedlings: growth and treatment costs

Philip M. McDonald Gary O. Fiddler



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Cover: Four years after initial release, Douglas-fir growth was significantly greater on an entire area sprayed with 2,4-D than it was on the untreated control (inset).

Publisher:

Pacific Southwest Forest and Range Experiment Station
P.O. Box 245, Berkeley, California 94701

September 1986

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IN BRIEF. . .

McDonald, Philip M.; Fiddler, Gary O. **Release of Douglas-fir seedlings: growth and treatment costs.** Res. Paper PSW-182. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1986. 9 p.

Retrieval Terms: vegetation management, regeneration, deerbrush, Douglas-fir, manual and chemical treatments, Klamath National Forest, California

Should a plantation be released? And if released, what would be the tradeoffs between stem caliper growth of Douglas-fir seedlings and treatment costs? Such questions often are asked by foresters and plantation managers.

A 3-year-old plantation on the Klamath National Forest in northern California was released from deerbrush by several manual and chemical techniques: grubbing shrub and herbaceous seedlings in a 2-, 4-, and 6-foot (0.6-, 1.2-, and 1.8-m) radius around Douglas-fir seedlings; and applying 2,4-D as a direct spray in a 3-foot (0.9-m) radius around seedlings and throughout an entire one-seventh acre (0.06 ha) area. Treatments were applied twice at a 2-year interval.

Four years after the first treatment, Douglas-fir stem caliper at 12 inches (30 cm) above mean ground line differed significantly (0.69 ± .30 inch or 1.75 ± .76 cm) between the entire area (one-seventh acre) directly sprayed with 2,4-D and the untreated control. Additional analyses, which compared various combinations of treatment means indicated by the data, showed significant differences in Douglas-fir seedling survival (46.5 ± 19.5 percent) and stem caliper (0.58 ± .32 inch or 1.47 ± .81 cm). In addition, biological data such as density, cover, height, and internal moisture stress of deerbrush, and annual stem caliper increment, annual height increment, and internal moisture stress of Douglas-fir, suggest that Douglas-fir will show additional response to the treatments in the near future.

Costs for two applications of each treatment ranged from \$46 to \$617 per acre (\$114 to \$1525/ha), with grubbing a 6-foot (1.8-m) radius being the most expensive and spraying the entire area with 2,4-D the least expensive. Grubbing small radii (less than 5.0 feet or 1.5 m) around Douglas-fir seedlings did not appear to be effective because roots of "edge" plants rapidly extended into the cleared area. Douglas-fir seedlings competing with many shrubs had smaller stem caliper increments than did seedlings with at least some growing space. Seedlings in the control, for example, had to sacrifice stem caliper and live crown development for height extension—average stem caliper growth during the study increased an average of 35 percent; average height, by 168 percent.

Information collected on growth dynamics and internal moisture stress relationships of deerbrush add to our knowledge on the ecology of this widespread and highly competitive shrub.

INTRODUCTION

The job of the forester often is challenging, especially because information on shrub ecology and growth rates above- and below-ground is lacking. Also lacking are effective and available shrub control methods and quantified estimates of the effect of woody shrubs on conifer seedling survival and growth in specific environments. In addition, forestry today is complicated by often-conflicting biological, economic, and managerial goals. The conflict between cost and desired growth response is particularly perplexing.

When a forest fire destroys a timber stand, it sets in motion a sequence of events that greatly influences subsequent vegetation and, therefore, establishment of a productive forest of desired species. On an area in northern California seared by wildfire, deerbrush (*Ceanothus integerrimus* H. & A.) in a 3-year-old plantation of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) was treated by manual and chemical methods. Four years later, density, cover, height, and internal moisture stress of deerbrush; and stem caliper, height, and moisture stress of Douglas-fir were measured. Deerbrush apparently was better suited to dominate in the postfire environment of the study area: in the control, average deerbrush height was 184 percent of that of Douglas-fir seedlings after 3 years. This fact and results from the study reported here show that not treating deerbrush would mean loss of the plantation.

This paper presents results on the cost and effectiveness of various manual and chemical release treatments. Managers can match the growth response of their conifer seedlings to the treatment best suited to their particular goals and budget. Stem caliper, rather than seedling height, was used for this comparison because it better expresses the effects of vegetative competition.

STUDY LOCATION AND ENVIRONMENT

The study reported here was part of a National Administrative Study on vegetation management begun in 1980 in northern California (Fiddler and McDonald 1984). The study area, located on the Salmon River District of the Klamath National Forest, is in the southern part of the area burned by the Hog Fire in August 1977. Before the fire, a well-stocked stand of mostly young-growth Douglas-fir was present, as well as scattered trees of California black oak (*Quercus kelloggii* Newb.), canyon live oak (*Quercus chrysolepis* Liebm.), and Pacific madrone (*Arbutus menziesii* Pursh).

After the fire, dormant seeds of deerbrush germinated by the thousands and a dense stand of shrubs began to occupy the area. Deerbrush was the most abundant vegetative species and constituted the major threat to conifer seedling establishment and growth. Seedlings of greenleaf manzanita (*Arctostaphylos patula* Greene) also were present, but distribution was clumpy. Overall, they numbered less than 500 per acre (1235/ha). Next in abundance were several grasses (*Bromus, Festuca, Elymus,* and *Avena* spp.). Pioneer herbaceous plants of scattered distribution and low abundance included species from the genera *Madia, Mimulus, Stephanomeria, Tragapogon, Montia,* and *Centaurea.*

Climate of the study area, which is located at about 2400-feet (732-m) elevation, is characterized by long, hot summers and cool, moist winters. Temperatures range from 18 to 110 °F (-8 to 43 °C) with a mean of 65 °F (18 °C). The growing season is about 120 days. Precipitation averages about 43 inches (1092 mm) per year. Some snow falls in the study area but melts quickly.

The soil has been identified as part of the Holland-Skalan association and is 2 to 4 feet (0.6 to 1.2 m) deep from a shale parent material. All duff and litter on the forest floor were consumed by the fire. Debris from standing dead trees and dead leaves from deerbrush shrubs, however, are slowly replenishing organic matter on the area. The general aspect of the plantation is south with slopes of 30 to 40 percent.

Based on the height-age relationship of Douglas-fir, site quality of the study area before burning was middle III (McArdle and others 1961). Because of loss of organic material, coupled with the hot south aspect, this area became a harsh site for Douglas-fir seedling establishment. Shade from dead trees probably benefited seedling survival, while competition for scarce resources by the abundant deerbrush probably lowered it. As a whole, the study area was fairly uniform in terms of aspect, slope, and site quality.

Two-year-old Douglas-fir seedlings from a local seed source were hand planted in March 1978. Survival in spring 1980 was 80 percent—a reflection of good growing stock, a good job of planting, and a site initially devoid of nearly all vegetation because of the fire.

TREATMENT AND STUDY METHODS

The study, begun in fall 1980, includes data recorded annually through the 1984 growing season. Total study length is planned for 10 years.

The experimental design was completely randomized with one-way treatment structure. Confidence intervals for the difference between any two treatments—designated as ($\overline{D} \pm w$), where $\overline{D}$ equals the difference between treatment means, and w equals the half-width of the confidence interval—were calculated by the Tukey method based on an analysis of variance model. The confidence interval can be used to present the best information available on the range of values within which the expected difference is estimated (with 95 percent confidence) to lie. Because information is gathered from permanent plots measured each year, the data are not truly independent. The α levels or type I errors given for various tests apply to each measurement and year separately. The overall error rate could increase by as much as the given amount for each measured variable each year.

Treatments, each replicated three times, included three manual, two chemical, and an untreated control. A replicate consisted of about one-seventh acre (0.06 ha) on which were 30 to 40 Douglas-fir seedlings surrounded by two to three rows of buffer (seedlings receiving similar treatment). In all treatments, the equivalent of 200 to 250 "crop trees" per acre (494 to 610/ha) were flagged. As their name implies, these were thrifty seedlings that had good potential of becoming harvestable trees. Small, misshapen and discolored seedlings were not part of the study—their chance of being alive at the end of the study was remote, given the large population of burgeoning deerbrush.

Manual treatments consisted of grubbing out shrub and herbaceous seedlings and snipping occasional hardwood sprouts. The manual treatments were designed to test the treatment of different circular areas having a 2-, 4-, or 6-foot (0.6-, 1.2-, or 1.8-m) radius around crop trees. Each treatment was applied twice—the most commonly used treatment frequency for combating woody shrubs in this area. The Douglas-fir seedlings were initially released in August 1980. Timing of the second set of treatments (May 1983) was dictated by encroachment of older deerbrush seedlings into cleared growing space and establishment of new deerbrush seedlings on cleared ground.

Chemical treatment was with 2,4-D, the herbicide most often applied to forest plantations in California when the study began.[1] It was applied in ester form directly from backpack apparatus at the rate of 3 pounds (1.4 kg) acid equivalent in a total of 10 gallons of solution per acre (18 L/ha). The chemical was applied to a 3-foot (0.9-m) radius around each crop tree and to those areas where the entire one-seventh acre was designated for treatment. Initial application was in June 1981 and again in May 1983. A plastic bag was placed over each Douglas-fir seedling to protect it from the herbicide.

An untreated control served to show the postfire response of natural vegetation and its effect on planted Douglas-fir seedlings.

Production data were gathered separately for each treatment and round of application, then combined. The basis for production was hourly records; the basis for cost was $7.50 per hour—the rate for a WG-1 laborer, U.S. Department of Labor, as of June 1984.

Sampling intensity was five randomly selected plots in each replication. Plots were centered around seedlings and were circular with 2-, 3-, 4-, or 6-foot radius, and 1 milacre (4 m^2) for entire area treated and control. In addition, about 25 Douglas-fir seedlings having potential as crop trees in each replicate were measured annually for stem caliper at 12 inches (30 cm) above mean ground line and checked for insect depredation and damage from 2,4-D.

Vegetation was measured annually for density, foliar cover (the sum of shadows that would be cast by leaves and stems of individual species), and average dominant height (average of the three tallest stems measured from mean ground line to bud). Treatment means were calculated each year and plotted graphically. Data were statistically analyzed each year.

Internal moisture stress of Douglas-fir, deerbrush, and greenleaf manzanita seedlings was determined to help explain their response to the treatments. Xylem sap tension was measured with a Scholander pressure chamber (Scholander and others 1965) on August 24 and 25, 1982—typical cloudless days at the end of a long, hot, dry summer, and a time of maximum physiological stress. Predawn moisture stress, maximum stress, and duration of maximum stress should be at or near peak at this time of year.

Sampling took place well before dawn and continued until late afternoon. Time and distance considerations mandated that only one replication be sampled. For this reason and because of the ever-changing amount of xylem sap tension in the plant, no statistical analysis of differences among treatments was possible. Sampling intensity was three randomly selected seedlings of each species in each treatment. Consequently, three twigs of each species were tested in the pressure chamber at each measurement time throughout the day. For sampling deerbrush on areas where a radius was prescribed, plants rooted on the very edge of the radius were measured, as were plants further back.

Each twig was placed in a sealed plastic bag. The elapsed time between cutting in the field and placement in the chamber did not exceed 3 minutes. Every third sample was measured twice in the chamber as a check on technique and working order of the equipment. "Plant moisture stress" in atmospheres is used in this paper to express pressure chamber values (Waring and Cleary 1967) because it is positive, direct reading, and most familiar to biologists in the field.

[1]This paper neither recommends the pesticide uses reported nor implies that they have been registered by the appropriate governmental agencies.

RESULTS

Douglas-fir

Differences in Douglas-fir and shrub seedling response to the various treatments were apparent in 1984 *(fig. 1)*, the first year that any measured parameter differed significantly among treatments. Differences among treatments were not significant for Douglas-fir survival or height, but were significant for stem caliper *(table 1)*. A Tukey method of analysis showed that stem caliper of Douglas-fir seedlings differed significantly between the entire area treated with 2,4-D and the untreated control (0.69 ± 0.30 inch).

Additional analyses (Scheffé tests) involved testing combinations of treatment means suggested by the data for significant differences (Snedecor and Cochran 1980). Combinations were least intensive treatments (2- and 4-ft manual, 3-ft chemical), most intensive treatments (6-ft manual, entire plot chemical), and control.

Douglas-fir survival differed significantly from the control in both the most intensive (46.5 ± 19.5 pct), and least intensive (37.7 ± 18.3 pct) treatments, but not from each other (8.5 ± 14.5 percent) *(table 1)*. Height did not differ. Stem caliper differed significantly between the most and least intensive treatments (0.31 ± 0.24 inch or 0.79 ± 0.61 cm) and the control (0.58 ± 0.32 inch or 1.47 ± 0.81 cm). The least intensive treatments did not differ significantly from the control (0.27 ± 0.28 inch or 0.69 ± 0.71 cm).

Two possible agents affecting seedling height were deer browsing and damage from 2,4-D. A resident deer population was estimated at 20 animals per square mile (7.7/km^2). From December through March, these numbers doubled (Bergstrom 1985). In spite of the deer, only one Douglas-fir seedling in one of the controls suffered height damage in 1981. Some hedging of deerbrush was noticed each year. No Douglas-fir seedlings were injured by 2,4-D.

To evaluate growth patterns and to check for possible shock after treatment, we further examined stem caliper and height of Douglas-fir seedlings by analyzing annual increments by treatment. No indication of shock was discernible for stem caliper or seedling height after either treatment application *(table 2)*. In general, average stem caliper growth, in the range of 0.11 to 0.53 inches (0.4 to 1.4 cm) per year, increased through 1983 but decreased in 1984. This decrease could reflect unusually high caliper growth in 1983 in response to an abnormally wet spring. In contrast, spring 1984 was near normal and growth of Douglas-fir stems was proportionately lower. Annual height growth of the various treatments showed a general pattern of successively larger increments each year in the range of 0.38 to 1.97 feet (12 to 60 cm), apparently without regard to weather.

Predawn minimum moisture stress of Douglas-fir seedlings ranged from 10.8 to 24.8 atmospheres and maximum stress from 22.5 to 31.3 atmospheres *(table 3)*. Because sampling

Table 1—*Douglas-fir seedling survival, height, and caliper, Klamath National Forest, 1984*

Treatment	Survival	Height	Caliper
	Pct	*Ft*	*Inches*
Manual			
2-ft radius	77	4.53	0.94
4-ft radius	89	4.91	1.06
6-ft radius	89	5.78	1.27
Chemical			
3-ft radius	73	5.38	1.20
Entire area	88	5.62	1.49
Control	42	4.79	.80
Standard error	7	.58	.11

Table 2—*Annual stem caliper and height growth of Douglas-fir seedlings, 1981-1984 growing seasons*

Treatment	Growth			
	1981	1982	1983	1984
	Caliper *(inches)*			
Manual				
2-ft radius	0.14	0.14	0.26	0.23
4-ft radius	.17	.17	.28	.28
6-ft radius	.17	.23	.39	.31
Chemical				
3-ft radius	.21	.21	.32	.28
Entire area	.20	.20	.42	.53
Control	.11	.19	.14	.17
Standard error	.03	.03	.04	.05
	Height *(feet)*			
Manual				
2-ft radius	0.49	0.43	0.69	1.30
4-ft radius	.40	.51	.83	1.55
6-ft radius	.44	.61	1.15	1.97
Chemical				
3-ft radius	.43	.66	.89	1.65
Entire area	.38	.67	1.09	1.95
Control	.50	.73	.79	1.34
Standard error	.08	.10	.11	.19

Table 3—*Moisture stress (atm) and standard error (SE) of Douglas-fir seedlings at Pacific standard time (P.s.t.), August 24-25, 1982*

Treatment	Minimum			Maximum		
	Atm	SE	P.s.t.	Atm	SE	P.s.t.
Manual						
2-ft radius	24.8	1.5	3:49 a.m.	30.3	1.4	10:56 a.m.
4-ft radius	20.2	.2	3:04 a.m.	31.3	1.0	10:03 a.m.
6-ft radius	14.3	.3	3:35 a.m.	26.2	.8	10:37 a.m.
Chemical						
3-ft radius	18.0	1.7	4:03 a.m.	26.5	1.4	11:10 a.m.
Entire area	10.8	1.2	6:03 a.m.	22.5	.8	3:57 p.m.
Control	20.5	3.0	3:15 a.m.	28.7	.3	10:22 a.m.

A

was possible only in one replication, the standard errors *(table 3)* represent sampling error rather than experimental error. When compared with the most intensive treatments, internal moisture stress of Douglas-fir seedlings in the least intensive treatments, in general, was higher before dawn, peaked earlier, had higher maximum values, and was of longer duration *(fig. 2A)*. Maximum stress in entire area sprayed with 2,4-D did not occur until 3:57 p.m. P.s.t.—much later than for other treatments and physiologically significant because the duration of high stress was shorter.

Deerbrush

Because deerbrush was the most abundant competitive plant species, several relationships for it are presented. In fall 1980 or after three full growing seasons, deerbrush plants in the untreated control averaged 45,467 plants per acre (112,349/ha), had foliar cover of 48 percent, and were 3.3 feet (1 m) tall *(table 4)*. After four additional growing seasons, deerbrush plants had decreased an average of 65 percent while cover had increased an average of 32 percent and height 97 percent. Apparently, the trend was to fewer but taller and wider plants.

Statistical analyses of deerbrush density, cover, and height tested whether the treatments differed from the control and whether they continued to do so in spite of shrub regrowth. Tukey analyses of deerbrush density and cover showed that deerbrush seedlings in the control differed significantly from counterparts in the other treatments *(table 5)*—being at least three times more dense on the average and having five times more foliar cover. A Tukey analysis of deerbrush height indicated that deerbrush seedlings in the control differed significantly from deerbrush seedlings in the treatments: 2-ft radius, 6-ft radius, and entire area sprayed with 2,4-D. Differ-

B

Figure 1—Differences in Douglas-fir seedlings were apparent among treatments in 1984: *(A)* 2-foot radius manually cleared, *(B)* 4-foot radius manually cleared, *(C)* 6-foot radius manually cleared, *(D)* 3-foot radius sprayed with 2,4-D, *(E)* entire area sprayed with 2,4-D, and *(F)* untreated control.

C

D

E

F

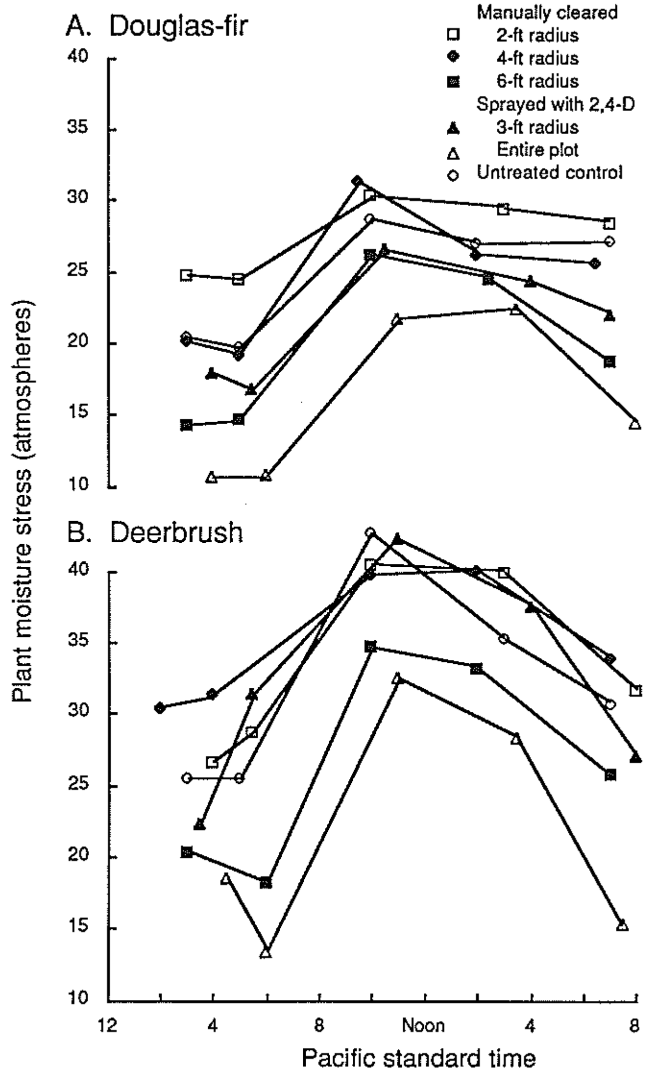

Figure 2—Diurnal trend of moisture stress, August 24-25, 1982, shows that duration of high stress was more a factor for Douglas-fir *(A)* than it was for deerbrush *(B)*. Standard errors applicable to differences between treatments could not be estimated.

Table 4—*Density, cover, and height, with standard errors (SE), of deerbrush in the control, and overall difference 1980-1984*

Year	Density	SE	Cover	SE	Height	SE
	Plants/acre		*Pct*		*Ft*	
1980	45,467	13,357	48	17	3.3	0.2
1981	38,289	10,451	49	12	4.2	.3
1982	19,378	6,216	48	14	4.6	.1
1983	19,356	5,080	61	8	5.9	.2
1984	15,978	4,424	64	11	6.5	.3
Difference (pct)	-65		32		97	

Table 5—*Deerbrush density, cover, and height, Klamath National Forest, 1984*

Treatment	Density	Cover	Height
	No./acre	*Ft²/acre*	*Ft*
Manual			
2-ft radius	3,465	5,083	2.19
4-ft radius	5,257	5,568	3.01
6-ft radius	2,003	1,823	2.39
Chemical			
3-ft radius	411	617	3.85
Entire area	133	67	1.10
Control	15,978	27,689	6.48
Standard error	1,553	1,291	0.64

ences among treatments and confidence intervals (95 percent) are shown for deerbrush density, cover, and height *(table 6)*.

Predawn minimum moisture stress of deerbrush seedlings ranged from 13.5 to 30.5 atmospheres and maximum stress from 32.5 to 42.7 atmospheres *(table 7)*. Ranking by treatment from least to most intensive resulted in the same relative order as for Douglas-fir seedlings: higher predawn values, earlier peaking *(fig. 2B)*, and higher maximum values for plants in least intensive treatments. Duration of high stress was less a factor for deerbrush than for Douglas-fir, probably because of more rapid falloff of stress after stomatal closure in deerbrush *(fig. 2)*.

Additional sampling showed that maximum stress of deerbrush on the edge of areas having a grubbed radius was lower than that of plants farther back. A possible reason for this is that roots of bordering deerbrush plants extended into the cleared area where competition was less. Such root extension of border plants helps to explain the high stress of Douglas-fir seedlings in areas having small radii. As a whole, both minimum and maximum stress values were higher for deerbrush than for Douglas-fir.

Production and Cost

Treatment effectiveness ultimately should be reported in terms of cost per conifer seedling of high growth potential. The cost and production data gathered in this study were found to be similar to average costs from contracts awarded on several National Forests in northern California, even though production rates in this study were from small areas and those from the National Forests were from large. The data were similar, probably because both the contracts and study involved equally experienced and motivated crews, and similar terrain, species of woody shrub, age of plantation, and type of treatment.

Production and cost values for the first and second sets of treatments combined showed that grubbing to a 6-foot radius took the most time and was the most expensive:

Treatment	Production time	Cost
	Man hours/acre	*Dollars/acre*
Manual		
2-ft radius	35	264
4-ft radius	73	549
6-ft radius	82	617
Chemical		
3-ft radius	8	60
Entire area	6	46

Dollars per acre are for labor only and do not include overhead or costs of the chemical and plastic bags.

Differences between any two treatments are presented for Douglas-fir stem caliper and production rates in 1984 *(table 8).* Confidence intervals for stem caliper, which are also presented, are useful to the forest land manager. They tell, in the example of the compared treatments (entire area and control), that one could expect with 95 percent confidence that the average stem caliper due to treatment in an environment similar to that in this study will be somewhere between 0.39 and 0.99 inch (0.99 and 2.52 cm) at age 7. Assume that a manager requires an increase of at least 0.3 inch (0.8 cm) in stem caliper before declaring a treatment worth applying. Further assume that a tight budget mandates that release costs be no more than $50 per acre ($124/ha), excluding the cost of the chemical. On the basis of these results, one can be reasonably certain that this standard can be obtained because the average stem caliper increase will be no lower than 0.39 inches (0.99 cm), and the treatment should be within budget (6 hours times $7.50 per hour, or $45).

DISCUSSION AND CONCLUSIONS

A fire on the Klamath National Forest changed a fully stocked young-growth stand of mostly Douglas-fir to a dense stand of deerbrush seedlings, occasional patches of greenleaf manzanita seedlings, and a few hardwood sprouts. Because the fire covered a large area, little or no natural conifer seed was available. Any natural conifer seedlings that did get

Table 6—*Differences between treatment means plus or minus half-width of 95 pct confidence interval ($\overline{D}$±w) for deerbrush density, cover, and height, 1984*

Treatments compared	Density		Cover		Height	
	No./acre		*Ft²/acre*		*Ft*	
Entire area chem., control	15,845 ±	4,264	27,622 ±	3,543	5.38 ±	1.76
3 ft chem., control	15,567	4,264	27,072	3,543	2.63	1.76
6 ft man., control	13,975	4,264	25,866	3,543	4.09	1.76
4 ft man., control	10,721	4,264	22,121	3,543	3.47	1.76
2 ft man., control	12,513	4,264	22,606	3,543	4.29	1.76
Entire area chem., 3 ft chem.	278	4,264	550	3,543	2.75	1.76
Entire area chem., 6 ft man.	1,870	4,264	1,756	3,543	1.29	1.76
Entire area chem., 4 ft man.	5,124	4,264	5,501	3,543	1.91	1.76
Entire area chem., 2 ft man.	3,332	4,264	5,016	3,543	1.09	1.76
6 ft man., 4 ft man.	3,254	4,264	3,745	3,543	0.62	1.76
6 ft man., 2 ft man.	1,462	4,264	3,260	3,543	0.20	1.76
6 ft man., 3 ft chem.	1,592	4,264	1,206	3,543	1.46	1.76
3 ft chem., 4 ft man.	4,846	4,264	4,951	3,543	0.84	1.76
3 ft chem., 2 ft man.	3,054	4,264	4,466	3,543	1.66	1.76
4 ft man., 2 ft man.	1,792	4,264	485	3,543	0.82	1.76

Table 7—*Moisture stress (atm) and standard error (SE) of deerbrush seedlings at Pacific standard time (P.s.t.), August 24-25, 1982*

Treatment	Minimum			Maximum		
	Atm	SE	P.s.t.	Atm	SE	P.s.t.
Manual						
2-ft radius	26.7	3.9	3:56 a.m.	40.5	1.5	3:16 p.m.
4-ft radius	30.5	1.8	3:11 a.m.	40.1	0.2	2:35 p.m.
6-ft radius	18.3	2.4	5:30 a.m.	34.7	0.2	10:47 a.m.
Chemical						
3-ft radius	22.3	3.0	4:07 a.m.	42.3	0.6	11:47 a.m.
Entire area	13.5	2.8	6:13 a.m.	32.5	2.2	12:00 p.m.
Control	25.5	4.2	3:30 a.m.	42.7	1.7	10:30 a.m.

Table 8—*Treatment means and differences between treatments for stem caliper, and production rate, Douglas-fir, 1984*

Treatments compared	Stem caliper		Production rate[2]
	Treatment means	$\bar{D} \pm w$[1]	
	Inches		*Man hours/acre*
Entire area chem., control	1.49 - 0.80	0.69 0.30	6
3 ft chem., control	1.20 - .80	.40 .30	8
6 ft man., control	1.27 - .80	.47 .30	82
4 ft man., control	1.06 - .80	.26 .30	73
2 ft man., control	.94 - .80	.14 .30	35
Entire area chem., 3 ft chem.	1.49 - 1.20	.29 .30	2
Entire area chem., 6 ft man.	1.49 - 1.27	.22 .30	76
Entire area chem., 4 ft man.	1.49 - 1.06	.43 .30	67
Entire area chem., 2 ft man.	1.49 - .94	.55 .30	29
6 ft man., 4 ft man.	1.27 - 1.06	.21 .30	9
6 ft man., 2 ft man.	1.27 - .94	.33 .30	47
6 ft man., 3 ft chem.	1.27 - 1.20	.07 .30	74
3 ft chem., 4 ft man.	1.29 - 1.06	.14 .30	65
3 ft chem., 2 ft man.	1.20 - .94	.26 .30	27
4 ft man., 2 ft man.	1.06 - .94	.12 .30	38

[1]Difference between means plus or minus half-width of the confidence interval.
[2]For two rounds of treatments.

started could not compete with the deerbrush, and none were found in the study area. Consequently, the legacy of the fire was to kill all the conifers and to stimulate a myriad of viable shrub seeds in the soil. Deerbrush, manzanita, and evergreen hardwoods have many morphological and physiological adaptations that allow them to capture resources, grow rapidly, and dominate after gross disturbance (McDonald 1982). In the control in 1980, for example, average height of deerbrush seedlings was 184 percent greater than that of Douglas-fir seedlings. Without release from deerbrush, Douglas-fir is at a disadvantage in capturing adequate resources and establishing dominance.

After the first year or two, mortality of Douglas-fir seedlings generally is low. For surviving seedlings, the primary effect of competing vegetation is reflected in stem caliper and height. Douglas-fir seedlings growing in an environment of many rapidly expanding shrubs had relatively small caliper and height increments, and, after four growing seasons, smaller and shorter stems. Seedlings that had at least some growing space with fewer competing shrubs had larger increments and thicker and taller stems. Mean diameter-height ratios of Douglas-fir seedlings by treatment were 0.014 for control, 0.017-0.019 for circular treatments, and 0.022 for entire area treated with 2,4-D. Stem caliper was expanding faster relative to stem height when the entire area was treated with 2,4-D. The opposite was true for Douglas-fir seedlings in the control. During the study, annual stem caliper growth increased an average of 55 percent but annual height increment for the same period increased by an average of 168 percent. Height was expanding faster than caliper for seedlings in the control. That Douglas-fir stem caliper in the entire-area treatment was the first to differ significantly from counterparts in the control was no surprise. In the Oregon Cascades where Douglas-fir seedlings compete with snowbrush (*Ceanothus velutinus* Dougl. ex Hook.), "release increases stem diameter more consistently than it does height" (Petersen and Newton 1982). Furthermore, young Douglas-fir released from snowbrush showed increased diameter growth before any height growth was measured (Gratkowski 1984).

Although several differences among treatments for Douglas-fir and deerbrush were quantified, precedent suggests that more will occur in the near future. The analyses of combined treatments suggested by the data indicate that differences in Douglas-fir survival are likely between treated seedlings and the control. Differences in stem caliper of Douglas-fir between most intensive and least intensive treatments and between most intensive and control suggest that additional treatments would differ between each other and from the control. Additional response among treatments are expected for two reasons. First, the effectiveness of the various treatments is a consequence of the number and vigor of deerbrush plants that become established after treatment. Large differences in deerbrush density, cover, and height among treatments should mean differential response by the conifer seedlings. And, because no more retreatments are planned, differences between most intensive and least intensive treatments should widen as trees in the least intensive treatment fall further and further behind. Second, internal moisture stress relationships were consistent with differences in growth among treatments for Douglas-fir seedlings.

Precedent, as well as similar ranking of treatments in the various groups of data from this study, suggests that more differences among treatments for Douglas-fir will occur. Douglas-fir survival, height, height increment, caliper, caliper increment, and internal moisture stress—or deerbrush density, and internal moisture stress—all show similar differentiation between most intensive and least intensive treatments.

Because of a recognized need for information on the genus *Ceanothus* (Conard and others 1985), we made a special effort to quantify growth dynamics and internal moisture stress for deerbrush. The large decrease in plant density and large increases in cover and height show the growth dynamics of deerbrush in the unaltered environment of the control. And the density, cover, and height relationships in the various treatments show recovery growth dynamics after manipulation. Such information may be useful to silviculturists elsewhere.

The stress of 42.7 atmospheres in the control exceeds the maximum value reported for deerbrush (Conard and others 1985) by 42 percent, adding one small but important bit of information on the competitiveness of *Ceanothus integerrimus.*

Without treatment, the entire area probably would resemble the control in 1984: 16,000 deerbrush seedlings per acre (39,536/ha), almost 6.5 feet (2.0 m) tall, with crowns that cover 65 percent of the area so closely that they cast a solid shadow. In this environment, only 42 percent of the original Douglas-fir seedlings are alive and in many instances are hard to find because they are under the deerbrush. Although Douglas-fir is noted for its capability to persist in such an environment, the odds for decreased growth and survival in the near future are high.

Timing of treatments affects response of Douglas-fir. Plantation release is recommended, but release earlier than age 3 probably would have been a better investment. Once shrubs reach this age, as in this study, it probably will take at least 7 more years for the effect of some treatments to be realized. Based on four long-term studies relating conifer seedling growth to shrub dynamics, McDonald and Oliver (1984: p. 88) concluded "ponderosa pine growth on a wide range of site qualities is best if woody shrubs are reduced to low levels when young and kept that way until less competitive vegetation becomes established." Treating shrubs when they are 1 or 2 years old likely would lessen the time needed to achieve full response for Douglas-fir as well.

That Douglas-fir seedlings survive and grow is not enough. Slow growth is money lost. Seedlings must have high growth potential and high odds of reaching harvestable size in a reasonable period. Identifying those treatments that enable Douglas-fir seedlings to have high growth performance at a reasonable cost, as discussed in this paper, is essential. Future reports will attempt to relate seedling potential after a longer timespan—10 years, for example—to the costs noted here. Also needed is a value that quantifies the maximum amount of growth that this site can support and a better definition of what is reasonable in terms of harvest size, time to harvest, and the costs of maintaining a maximum growth rate. Our future work will address these concerns.

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The Forest Service, U.S. Department of Agriculture, is responsible for Federal leadership in forestry. It carries out this role through four main activities:

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McDonald, Philip M.; Fiddler, Gary O. **Release of Douglas-fir seedlings: growth and treatment costs.** Res. Paper PSW-182. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1986. 9 p.

Foresters often lack information on growth of woody shrubs and their effect on conifer seedling survival and growth. Deerbrush (*Ceanothus integerrimus* H. & A.) was treated by several manual and chemical methods at age 3 and again at age 5 in a Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) plantation on a medium-quality site on the Klamath National Forest, California. Four years after initial release, Douglas-fir stem caliper at 12 inches (30 cm) above mean ground line differed significantly (0.69 ± 0.30 inch or 1.75 ± 0.76 cm) between an entire area (one-seventh acre) sprayed directly with 2,4-D and the untreated control. Additional analyses with combinations of treatment means indicated significant differences in Douglas-fir seedling survival and stem caliper among three manual and an additional chemical treatment. Differences among the six treatments, which are presented in 15 comparisons of stem caliper and treatment production rates, provide forest managers with growth and cost comparisons.

Retrieval Terms: vegetation management, regeneration, deerbrush, Douglas-fir, manual and chemical treatments, Klamath National Forest, California